Emissions Data for Aerosol and Earth-System Research

Discussion Draft

STEVEN J. SMITH
Joint Global Change Research Institute
College Park, MD

USGCRP

March 21, 2014

Outline

An idea that grew out of our experience producing historical emissions for the RCP/CMIP5 process several years ago.

Past Work

Background

    Motivation

    Goals

More Timely Data

    CMIP6

Flexible, Community Data System

    Overview/Approach

    Methodology

Summary

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

Smith, S.J., Pitcher, H., and Wigley, T.M.L. (2001) **Global and Regional Anthropogenic Sulfur Dioxide Emissions**. Global and Planetary Change 29/1-2, pp 99-119

Smith, S.J, R. Andres, E. Conception and J. Lurz (2004) **Sulfur Dioxide Emissions: 1850-2000** (PNNL-14537).

Lamarque, J. F; et al. (2010) **Historical (1850-2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: methodology and application** *Atmospheric Chemistry and Physics* **10** pp. 7017–7039. doi:10.5194/acp-10-7017-2010

Lamarque, J.-F., Kyle, P., Meinshausen, M., Riahi, K., Smith, S. J., Van Vuuren, E., Conley, A., Vitt, F. (2011) **Global and regional evolution of short-lived radiatively-active gases and aerosols in the Representative Concentration Pathways** *Climatic Change* **109** (1-2) 191-212. *doi:10.1007/s10584-011-0154-1*

Granier C, et al. (2011) **Evolution of anthropogenic and biomass burning emissions at global and regional scales during the 1980-2010 period** *Climatic Change* **109** (1-2) 163-190. *doi: 10.1007/s10584-011-0154-1*

Smith, SJ, J van Aardenne, Z Klimont, R Andres, AC Volke, and S Delgado Arias (2011) **Anthropogenic Sulfur Dioxide Emissions: 1850-2005** *Atmos. Chem. Phys.*, **11**, 1101–1116.

Klimont, Z, S J Smith and J Cofala (2013) **The last decade of global anthropogenic sulfur dioxide: 2000-2011 emissions** *Environmental Research Letters* **8** 014003. doi:10.1088/1748-9326/8/1/014003

Smith SJ and A Mizrahi (2013) **Near-Term Climate Mitigation by Short-Lived Forcers** *PNAS. doi: 10.1073/pnas. 1308470110.*

Gridded emissions of aerosol (BC, OC) and aerosol precursor compounds (SO_2, NO_x, NH_3, CH_4, CO, NMVOC) are key inputs for aerosol research and Earth System Models

- Needed for historical and future simulations, validation/comparisons with observations, historical attribution, and uncertainty quantification

The current historical dataset used by GCMs/ESMs (Lamarque et al. 2010) was a major advance in terms of consistency and completeness. This data, however, has a number of shortcomings.

- Only extends to 2000 with coarse temporal resolution (10-years)

- Time series for many of the species formed by combining different data sets leading to inconsistencies

- No comprehensive uncertainty analysis provided (available only for SO2 – Smith et al. 2011 and earlier BC/OC datasets – Bond et al. 2007)

- Methodology not consistent across emission species

- Not designed to be repeatable and easily updated

Scientific Research Support

- Regular updates of anthropogenic emissions (SO_2, BC, NO_x, CH_4, etc.)

- Consistent extrapolation over time (prevent spurious discontinuities)

- Consistent with country-level inventories (where desired/appropriate)

- Annual resolution with regular updates

- Facilitate greater temporal (seasonal) and spatial (e.g. US, China, Russia, sub-country) detail

- Transparent emission results (assumptions -> emissions)

- Facilitate cross-country comparison (EF consistency, trends)

Enable Scientific Advances

- Uncertainty analysis (X 3!)

- Short-Lived Climate Forcer Research

- GCM Validation and Uncertainty Quantification

- Near-term climate prediction and analysis

Global SO$_2$ Emissions
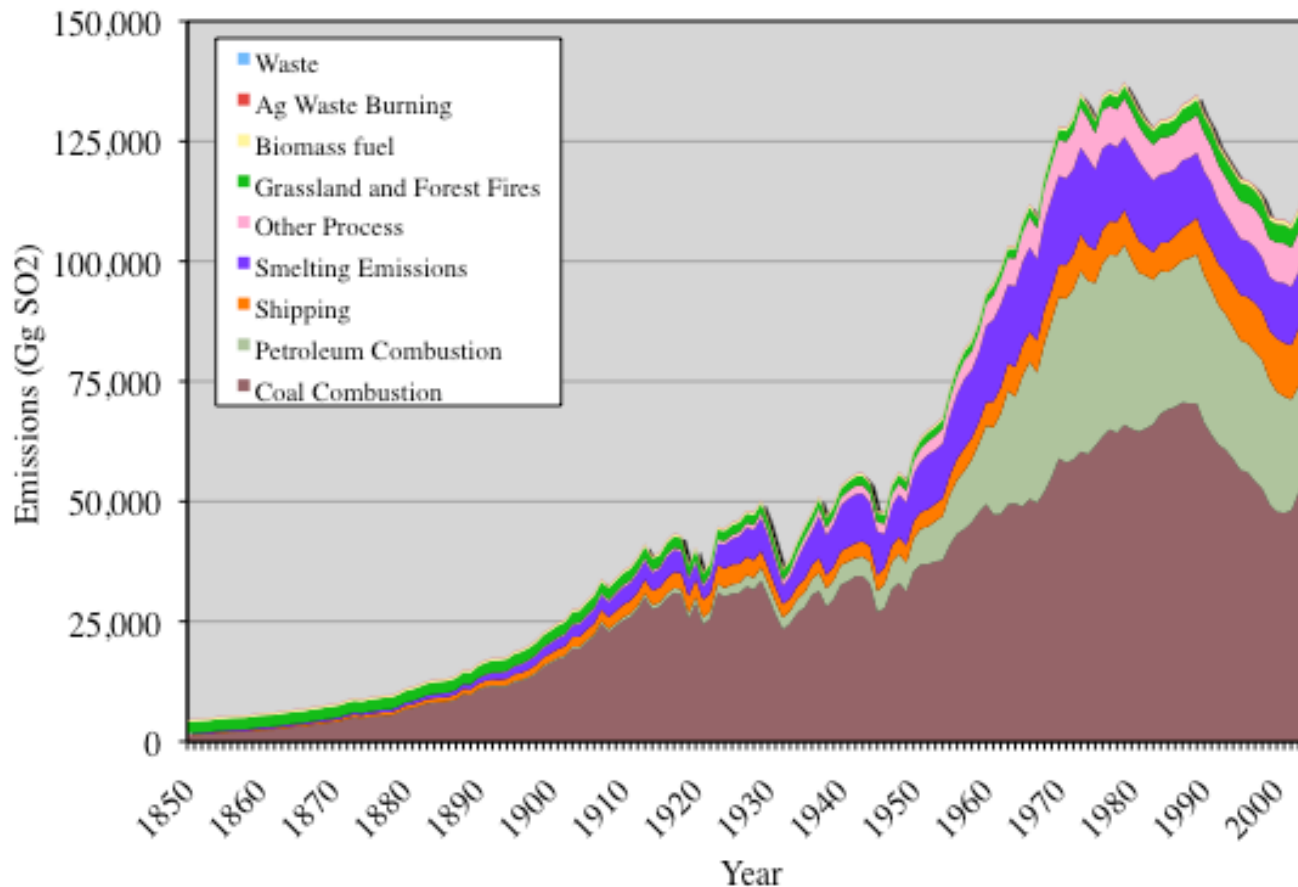
Annual estimates at country level from 1850-2005 using updated inventories, mass-balance, and driver data.

Gridded emissions every 10-years for RCP scenarios.
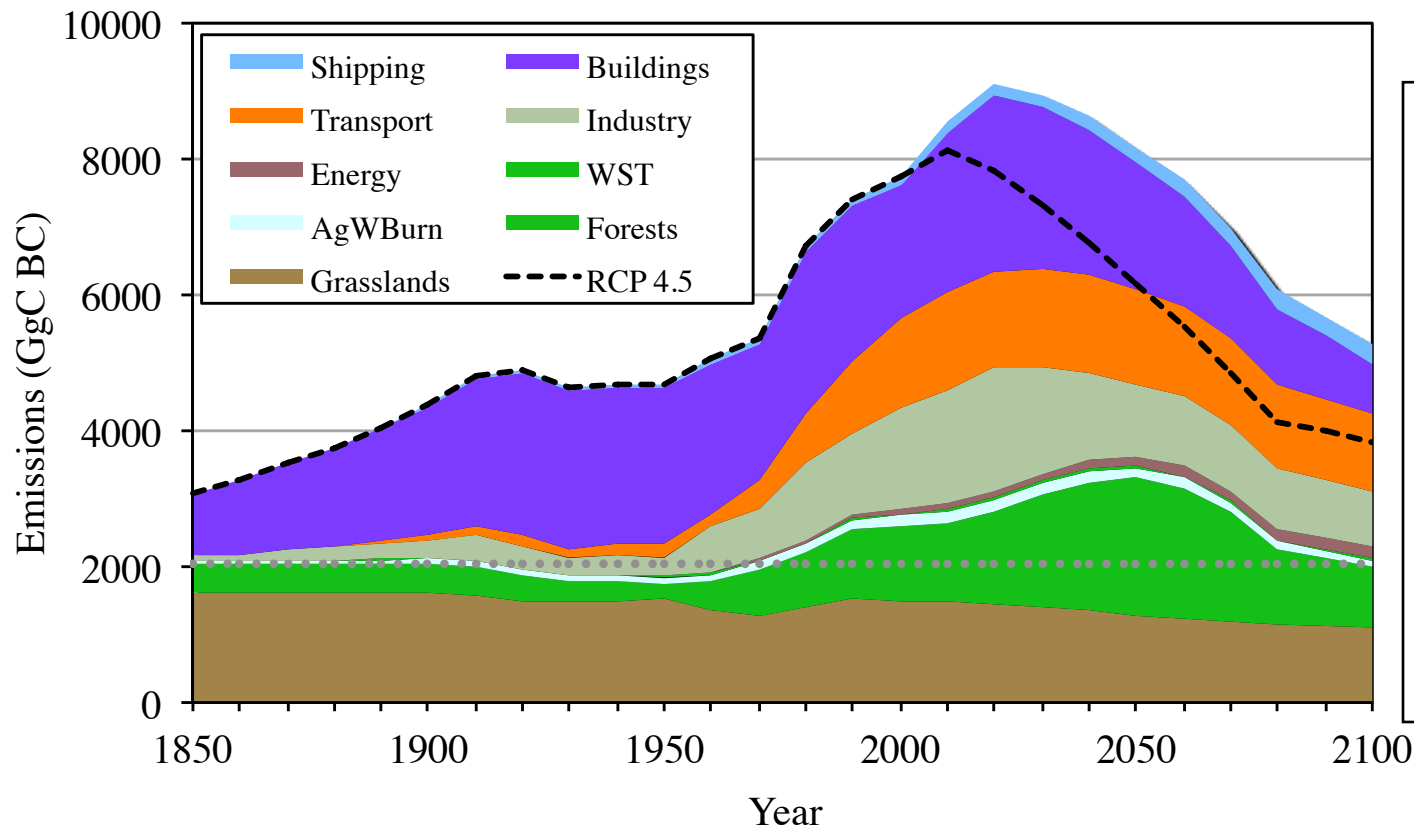
Smith et al (2011)

Fairly monotonic increase from 1950-1970

A number of global and regional features

World wars, great depression, collapse of FSU, recent-trends in China

6

Global BC Emissions

Decadal estimates from 1850-2000, RCP 4.5 projections from 2000-2100

Gridded emissions every 10-years for RCP scenarios.

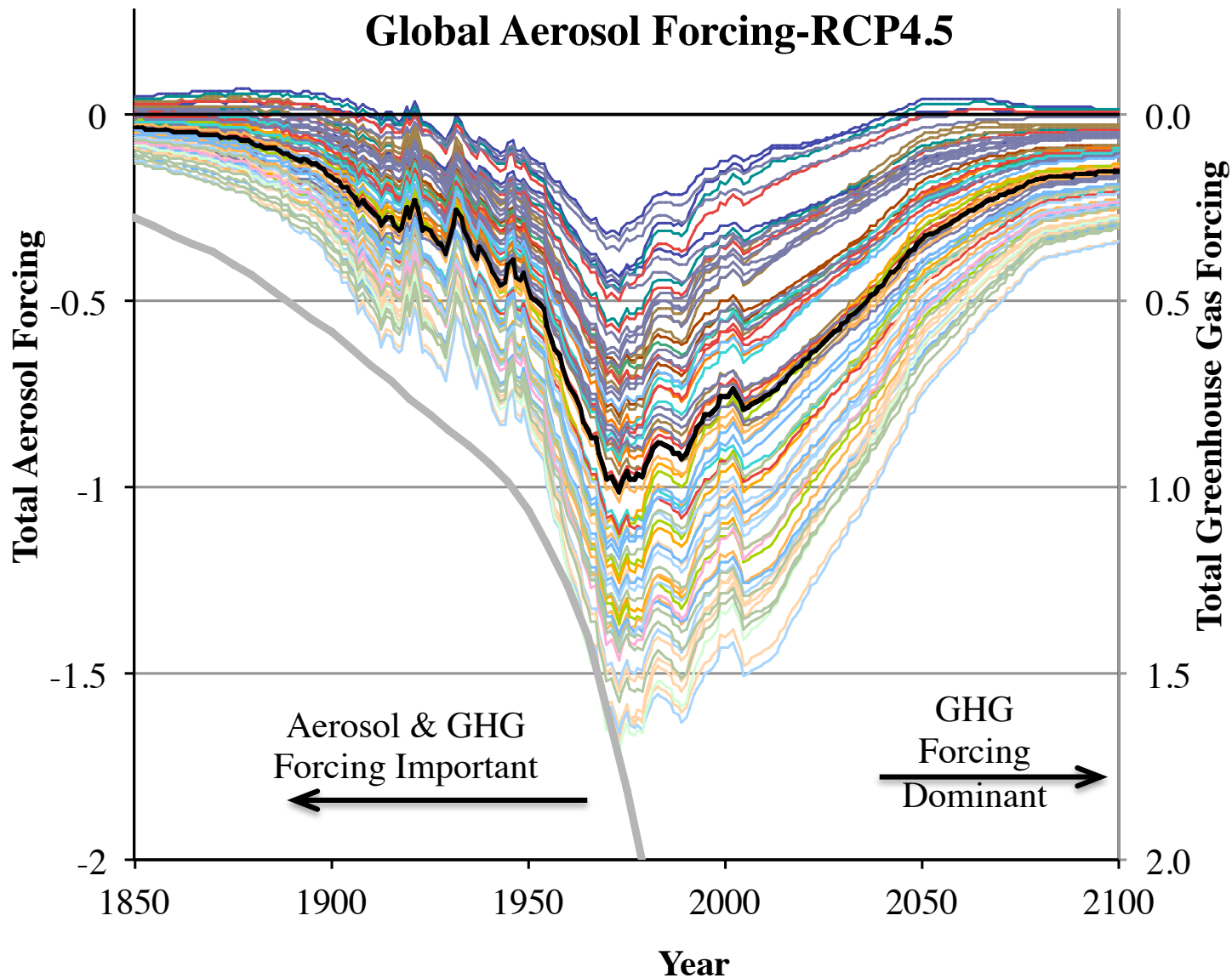Lamarque et al (2010), Thomson et al. (2011), Smith & Bond (2014)

Building sector dominates emissions historically

Key driver of seasonality (not included in RCP/CMIP5 inventory)

Transportation and industry increasingly important over 20th century

Less temporal detail, broadly consistent with SO2, but different methodology

7

There is a large amount of climate-relevant information not included in current emission data sets!

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Global Aerosol Forcing-RCP4.5

Aerosol & GHG Forcing Important ←

GHG Forcing Dominant →

Smith SJ and Bond, T. C. (2014) Two hundred fifty years of aerosols and climate: the end of the age of aerosols, Atmos. Chem. Phys. 14 537–549. doi:10.5194/acp-14-537-2014

Instead of this

Emissions

Historical Estimate
Projection
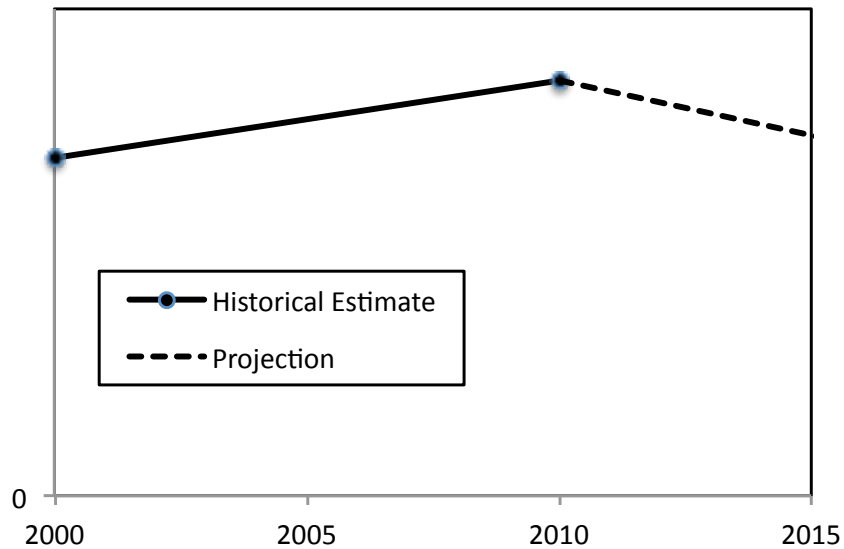
Produce This
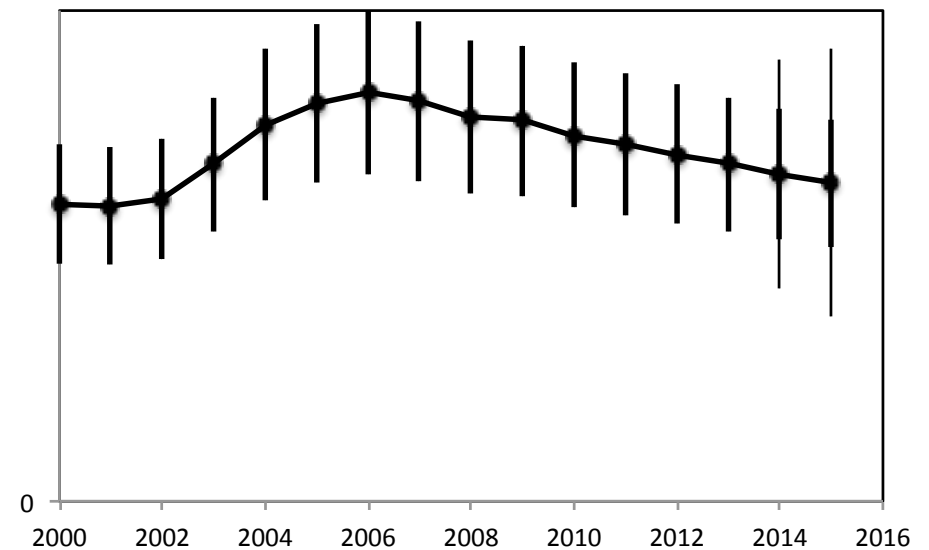
Emissions

MORE TIMELY EMISSIONS DATA

10

Example: Production of an inventory fall 2015.

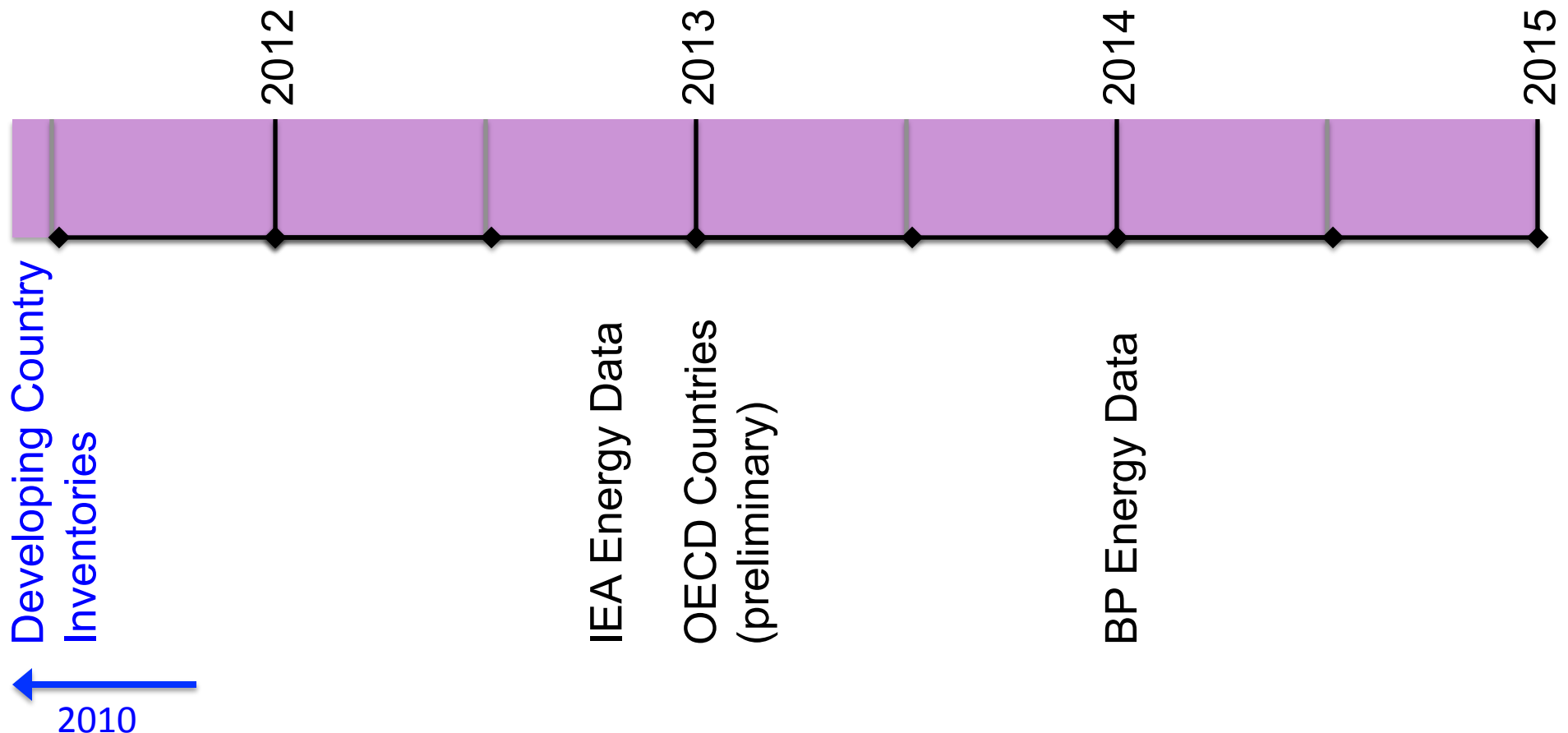## What data is available by mid-2015?

2012   2013   2014   2015

Developing Country Inventories

IEA Energy Data

OECD Countries (preliminary)

BP Energy Data

2010

Estimates to the previous full year are possible, but w/ larger uncertainty

Providing Data for Modelers

- If provide annual data, can provide information to a later year.

- Provide uncertainty estimates as automatic part of process!

    - Later years are more uncertain. Important that users understand this.

- Provide interpretation rules for harmonizing history to future projections.

What is Possible?

- Preliminary estimates up to previous year (Klimont et al 2013)

    - Using preliminary, not-sectoral, energy data

    - Extrapolation of emissions factor trends

    - Recent years will be more uncertain

    - Can repeat calc with previously released data to evaluate uncertainty

- Preliminary OECD country estimates available (accurate to ~10-20%) from 2 years prior.

- Developing country estimates lag is larger (up to ~5 years or more)

AN EMISSIONS DATA SYSTEM

13

Overview

- Complementary to existing efforts

- Open source code and (where possible) input data

- Annual updates of emissions

- Tool useful for emissions emissions research more broadly (uncertainty, regional emissions, etc.)

Approach

- Develop in the R open-source platform

- Focused on anthropogenic emissions (not open burning)

- First build system to produce updated SO2 estimates for aerosol research (building on Smith et al. 2011, Klimont et al. 2013)

- Will be built as expandable to other gases with addition of data files

- Methodologies from Smith et al. (2011) & Klimont et al. (2013)

Emissions Estimation System
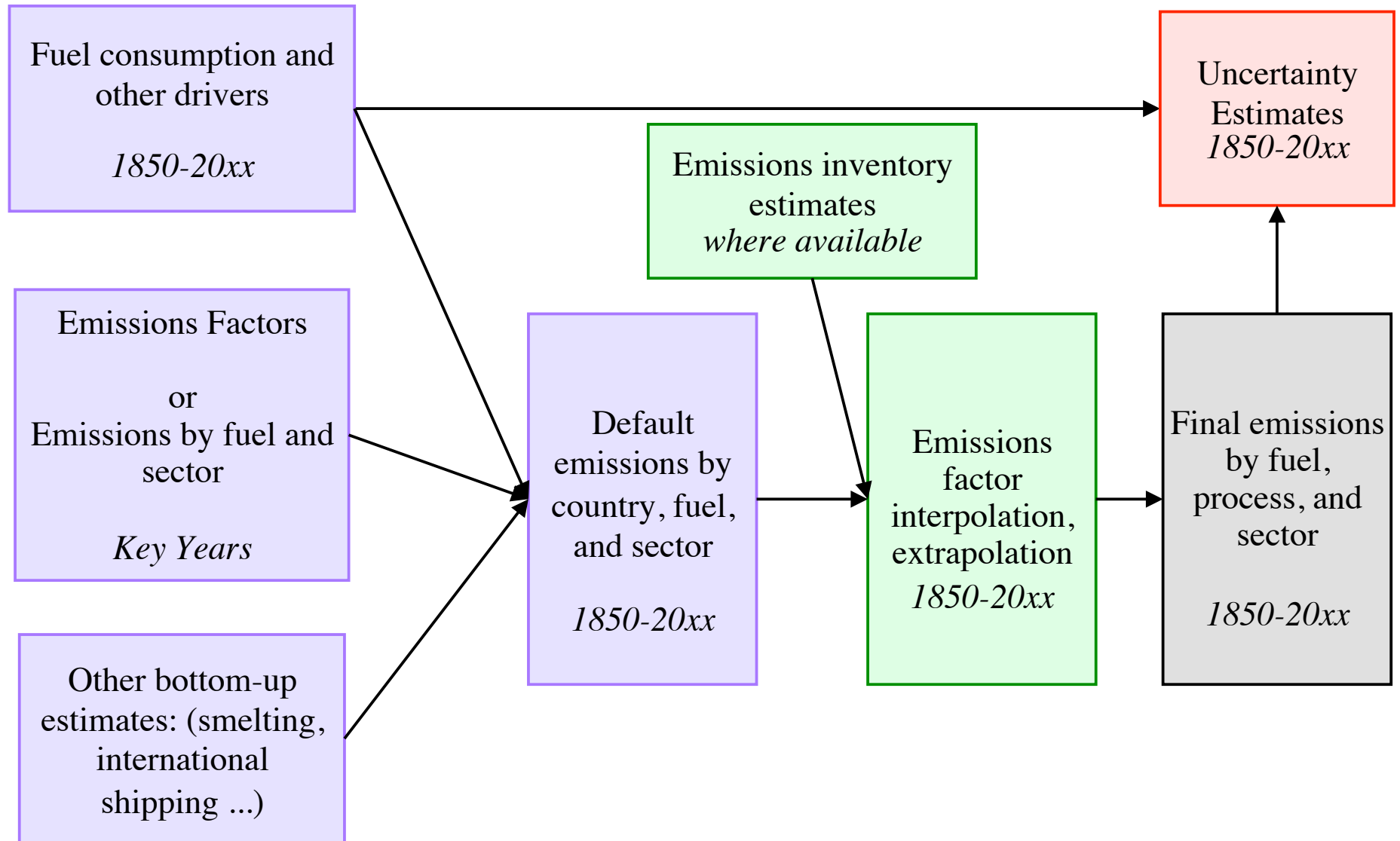
CMIP6 Coordination

CMIP6 Preparation

Emissions estimates will need to be provided for ESM and GCM historical model experiments

- Community wishes to have one central estimate up to the most recent year possible

- For this round, we wish to test emissions dataset before releasing to community

Coordination of overall effort for CMIP6 goes beyond production of historical anthropogenic emissions data

- Engage sectoral experts to provide latest spatially explicit estimates for special sectors such as aviation, shipping

- Coordination with production of grass and forest fire emissions

- Storage of emissions datasets (500 times previous requirements-PCMDI?)

- Coordination with IAM modeling groups

Because emission estimates are particularly uncertain for recent years, we could provide the following (as annual values for recent decades):

Emissions
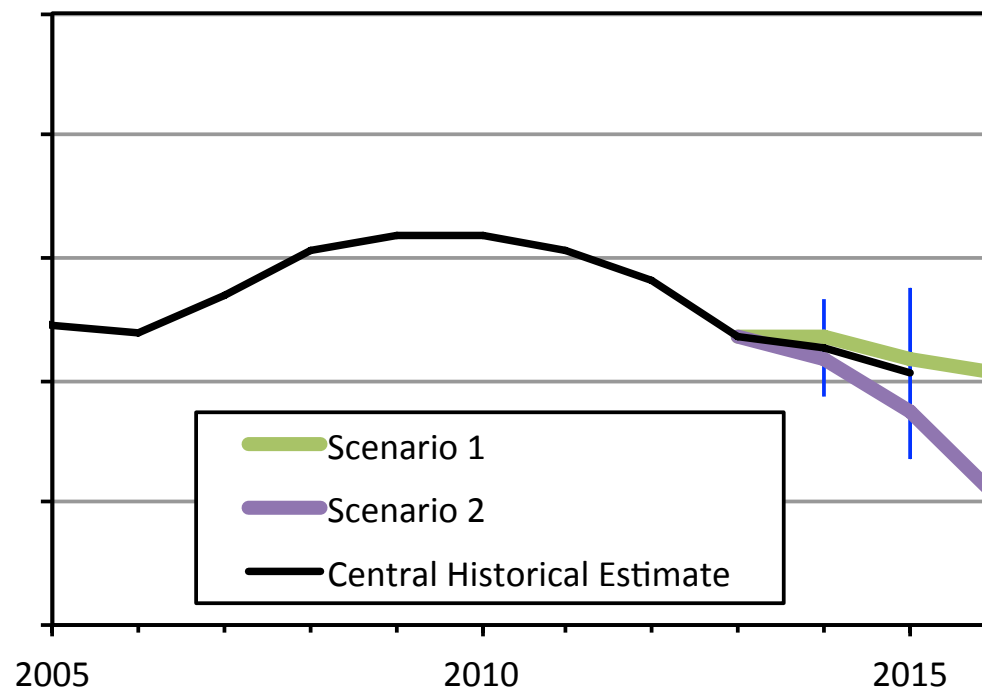
In fall 2016, a central estimate could be provided up to the previous year (yr -1)

Future IAM projections could be harmonized to:

- (yr-3) value – constrained to fall within the central estimate uncertainty.

- Harmonized to yr -1 value.

A potential timeline for staged release of data for CMIP6:
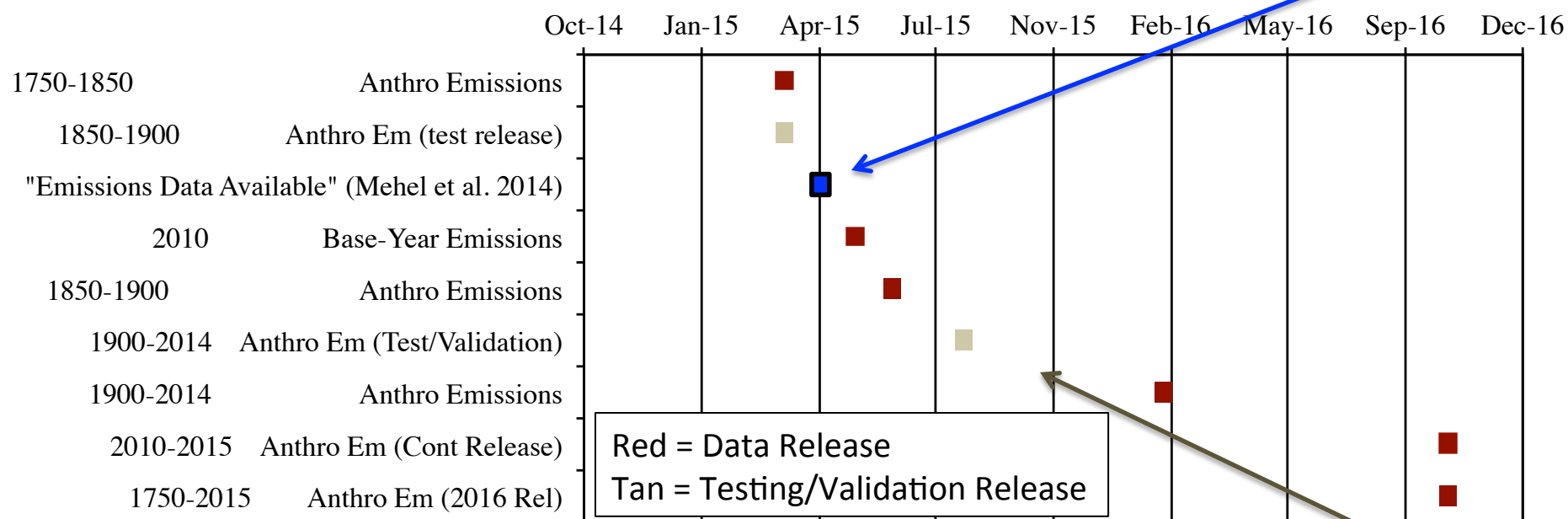
When CMIP modelers want this data.

CMIP6 Deliverable Timeline

		Oct-14	Jan-15	Apr-15	Jul-15	Nov-15	Feb-16	May-16	Sep-16	Dec-16
1750-1850	Anthro Emissions			■						
1850-1900	Anthro Em (test release)			■						
"Emissions Data Available" (Mehel et al. 2014)				■						
2010	Base-Year Emissions				■					
1850-1900	Anthro Emissions				■					
1900-2014	Anthro Em (Test/Validation)					■				
1900-2014	Anthro Emissions						■			
2010-2015	Anthro Em (Cont Release)									■
1750-2015	Anthro Em (2016 Rel)									■

Red = Data Release
Tan = Testing/Validation Release

Have built in time for testing/validation.

This timeline assumes full project funding by early fall 2014

- If funding comes in too slowly, then this timeline probably can't be met.
- If funding can come in faster, then this timeline can be moved up

19

Improved historical emissions data will also improve future scenarios:

- Base-year calibration values by fuel and sector (less need for interpolation)

- Recent trends to compare against projections

- Historical data to analyze past behavior (rates of emission control, relationship to economic growth, etc.)

- Historical data to use for hindcast experiments

Harmonization with future scenarios:

- Fairly detailed harmonization with gridded scenario data essential

- Harmonization with native IAM model output can be looser

  - *There is uncertainty in base-year emissions*

  - *Base-year uncertainty becomes less important over time into the future*

  - *Scenario data will be in coarser intervals*

SUMMARY

21

Summary

We propose an open-source emissions data system that can:

- Produce the most up to date anthropogenic aerosol and aerosol precursor emissions estimates

- Open data processes for community buy-in and verification

- Annual emission estimates in order to 1) capture timing of regional trends and 2) to provide as up to date estimates as possible

- Provide the uncertainty estimates needed for optimal use of data and for climate model UQ research

- Build on existing efforts (GAINS, EDGAR, REAS, country-level inventories) to provide data products and analysis needed for science advances and advance emissions estimation science.

- Publish methodology and results in peer-reviewed literature

Other Research

- As an open source system, other groups can add/modify code and data

END

Methodology

- Modular code and data construction (building from GCAM R-data system, make-file build system, etc)

- **Data-driven system**

- Initial focus on energy system, data-driven sub-modules for other drivers (ag/industry)

- Work at broad sectoral level, with selected detail (DOM, TRN, IND, ENE, Coking coal, etc.)

- Broad fuel categories (Hard coal, soft coal, gasoline, diesel, heavy oil, ...)

- Sub-modules for state/province level breakout.

- IEA country level (perhaps all UN countries instead)

Output

- Primary emission estimation system for SO2.

- Other emissions: extending/interpolating/analyzing emissions

Emissions for most recent years are always more uncertain

Inventory	1980	1990	1995	1996	1997	1999	2000	2002	2003	2004	2005	2006
Combustion												
Trends 1998	0%	0%	0%	42%	25%							
Trends 2000	0%	0%	0%	0%	0%	-21%	-4%					
Trends 2003	0%	0%	0%	0%	0%	0%	0%	####	-8%			
Trends 2006	0%	0%	0%	0%	0%	0%	0%	-8%	-5%	-2%	0%	0%
Process												
Trends 1998	0%	0%	0%	-29%	-29%							
Trends 2000	0%	0%	0%	10%	9%	36%	75%					
Trends 2003	0%	0%	0%	0%	0%	0%	0%	14%	21%			
Trends 2006	0%	0%	0%	0%	0%	0%	0%	0%	3%	7%	11%	11%
Highway												
Trends 1998	-46%	-48%	-35%	-32%	-32%							
Trends 2000	-46%	-47%	-35%	-31%	-30%	-28%	-29%					
Trends 2003	0%	0%	0%	0%	0%	0%	0%	3%	4%			
Trends 2006	0%	0%	0%	0%	0%	0%	0%	4%	7%	11%	16%	19%
Off-Highway												
Trends 1998	-13%	-15%	-15%	-17%	-14%							
Trends 2000	-13%	-15%	-15%	16%	18%	20%	16%					
Trends 2003	0%	0%	0%	0%	0%	0%	0%	8%	11%			
Trends 2006	0%	0%	0%	0%	0%	0%	0%	-1%	4%	9%	14%	21%
Total												
Trends 1998	-37%	-36%	-26%	-26%	-20%							
Trends 2000	-37%	-36%	-26%	-19%	-11%	-11%	-4%					
Trends 2003	0%	0%	0%	0%	0%	0%	0%	1%	2%			
Trends 2006	0%	0%	0%	0%	0%	0%	0%	-2%	2%	6%	10%	14%

Note: Column group header "Data Year" spans the year columns.

Data

- IEA energy statistics

    -- Can't release, but can give the 5-step instructions to import data

- Andres, Bond, UN historical estimates (need to work out release policy)

- BP energy data

- USGS minerals and metals

- Hyde historical data

- UNFCCC emissions reporting, Mylona, etc.

- And so on

- The RCP historical emissions were provided up to 2000

    -- Preliminary 2005 SO2 estimates provided to IAM modelers

- The RCP IAM projections were within the uncertainties of historical estimates.

Global Anthropogenic Sulfur Emissions